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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF THE DYNAMIC CHARACTERISTIC OF LAMINATED COMPOSITE PLATE HYBRID WITH STEEL

MUHSIN J. JEEWG[1], ABDAL-KAREEM F. HASSAN[2] & JAWAD K. ZEBOON[3]

[1]College of Engineering, Al-Nahrain University, Baghdad, Iraq

[2]College of Engineering, Al-Basrah University, Baghdad, Iraq

[3]Foundation of Technical Education, Iraq

ABSTRACT

The laminated composite plates are basic structural components in many varieties of engineering applications such as airplane wings, sport equipment, turbine blades as well as other applications in mechanical and civil industries. Computation of natural frequencies and mode shapes represent the important elements in dynamic analysis because these plates subjected to a variety of dynamic excitations. Four plates are made using the hand-lay process. Carbon fiber, stainless steel and polyester resin as a matrix are used for composite plates. Experimental dynamic tests are carried out using specimens of different volume fractions of steel. From the results the influence of steel volume fraction on the natural frequency is investigated. The experimental results are used to validate the results obtained from the finite element software ansys.

KEYWORDS: Laminated, Composite, Plates, Dynamic Analysis, Steel

INTRODUCTION

Composite materials are finding increasing application in transportation vehicles, aerospace, marine, aviation and other industries in recent decades. This is due to their excellent features, such as high strength-to-weight and stiffness-to- weight ratio.

An unlimited number of researchers have been developed numerous solution methods to analysis the dynamic behavior of laminated composite plates. In 1969 Ashton et al. [1, 2] used the so-called beam characteristic function to investigate the natural frequency of anisotropic plates. He gave some good results in certain boundary conditions of these plates. Zhong et al.[3] proposed an experimental test procedure in order to measure fundamental natural frequency of smart plates. Two types of laminated composite plates with unidirectional and woven SMAs were fabricated and their vibration characteristics were investigated by both impact vibration tests and theoretical analysis. Along with increasing of the application of finite element method, more and more authors used finite element method to analyses the vibration of plates. In 1978 Cawley and Adams [4] used finite element method to predict the natural frequency of these plates per missing for arbitrary edge condition even for all free edges plates. Ostachowicz et al. [5] studied the effect of the natural frequency of composite plates with embedded SMA actuators using a computation method. In this study, they proved that the natural frequency of the plates could be controlled by the embedded SMA actuators under a condition of heat applied. Bicos and Springer [6] equations are derived which describe the free damped vibrations of plates and shells made of laminated fiber-reinforced, organic-matrix composites. A finite element method is developed for obtaining solution to these equations.

The objective of this study is to understanding of the dynamic behavior of composite plates made from carbon fiber, matrix and hybrid with steel wires. In order to investigate the influence of the steel volume fraction on the dynamic

behavior of the components, experimental and numerical analysis using the finite element method have been carried out. The results are presented and discussed.

PRODUCTION OF THE LAMINATED SPECIMENS

Carbon fiber is used as reinforcement in the form of unidirectional and general purpose polyester resin as a matrix for the composite material of the laminated specimens. A stainless steel 316L material in the form of wires is used as a hybrid.

The steps of manufacturing the composite hybrid plates using hand lay-up process are described below [7].

Preparation of the Mould

The hand lay-up process is open molding technique used. The surface of the mold is through cleaned to be ready for the use, by removing any dust and dirt from it.

Application of the Release Agent

After the mold surface has been cleaned, the release agent is applied. Where, the mold surface is coated with a free wax using a smooth cloth. Then a film of polyvinyl alcohol (PVA) is applied over the wax using sponge. PVA is a water soluble material and 15% solution in water is used. When water evaporates, a thin film of PVA is formed on the mold surface.

PVA film is dried completely before the application of resin coat. This is very important as the surface of the final article will be marred with partly dried PVA film otherwise release will not be smooth.

Preparation of Matrix Material

The matrix material is prepared using general purpose polyester. Cobalt octane (0.35% by volume of resin) is added to act as accelerator and Methyl ethyl ketone peroxide (MEKP) (1%by volume) is added to act as catalyst. Resin, accelerator and catalyst are thoroughly mixed. The use of accelerator is necessary because without accelerator resin does not cure properly. After adding the accelerator and catalyst to the polyester resin, it has left for some time so that bubbles formed during stirring may die out. The amount of added accelerator and catalyst is not high because a high percentage reduces gel time of polyester resin and may adversely affect impregnation.

Preparation of the Reinforcement and Hybrid Steel Plate

A unidirectional carbon fiber with thickness (0.3 mm) is used as a reinforcement, which cut in four layers of required dimensions for each specimen. Also a required length and number of stainless steel wires cut to be placed in layers 2 and 3 for three specimens with different volume fractions, while the fourth specimen left without steel.

Preparation of the Laminated Plate

To prepare of laminated plate, the first layer of carbon fiber is laid then, the resin is spread uniformly over the fiber by means of a brush. The second layer of fiber is laid and a determined quantity of steel wires is distributed over the fiber and resin is spread uniformly over them by means of a brush. After second layer, to enhance wetting and impregnation, a teethed steel ruler is used to roll over the fabric before applying resin. This process is repeated till all the four fabric layers are placed. External pressure plate is used to apply pressure while casting or curing to enhance uniform thickness reached. The casting is carried out at room temperature for 24 hours and firmly removed from the mold to get a fine finished composite plate.

Preparation of the Test Specimens

After the cure process, test specimens are cut from the sheet of 4 ply laminate total (length 28 cm, width 28 cm) for aspect ratio equal (1) for aspect ratio equal (1) by using the cutting machine. The true dimensions used for test are (24 cm ×24 cm ×0.6 cm) length, width and thickness respectively; the 4 cm increased in length and width is used for supported. All the test specimens are finished by abrading the edges on a fin carbon or undam paper.

MATERIALS AND EXPERIMENTAL TEST SPECIMENS

Material Properties

The mechanical properties of the contents of the test specimens; carbon fiber, stainless steel 316L and polyester are listed in table 1.

These properties are young modulus (E_1in direction 1, E_2 in direction 2 and E_3 in direction 3), poisons ratio (v12), in plane shear modulus (G_12) and transverse shear modulus (G_13 and G_23) as referred in figure 1. This figure defines the material principle axes for a typical fiber reinforced lamina. Axis '1' is a long the fiber length and represented the longitudinal direction of the lamina, axis '2' and '3' represent the transverse in-plane and through the thickness direction respectively.

Table 1: Properties of Used Materials

Properties	Carbon Fiber	Polyester Resin	Steel 316l
E_1(GPa)	230	3	193
E_2(GPa)	15	3	193
E_3(GPa)	15	3	193
G_{12}(GPa)	27	1.6	77
G_{23}(GPa)	7	1.6	77
G_{13}(GPa)	7	1.6	77
ν_{12}	0.2	0.35	0.27
ρ(kg/m^3)	1790	1100	8000

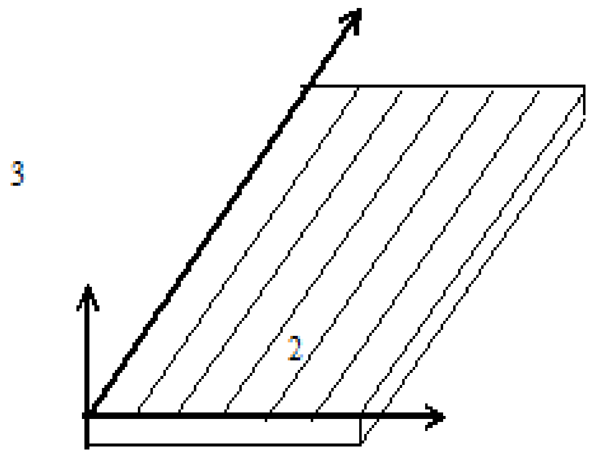


Figure 1: Lamina Reference Axes

Calculation the Volume Fraction of Components

The volume fraction of any component is the volume of the component relative to total volume of all the components. Since fiber, steel and matrix affect the materials properties therefore; they should be determined for each tested specimen and accounted for in predicting mechanical response. The fiber, steel and matrix volume fractions can be

determined by weighting, fiber and steel using an electronic balance and then calculating the weight of the matrix as follow; [7]

$$M_c = M_f + M_m + M_s\ ,\ Vf = \frac{M_f}{\rho_f}\ ,\ V_S = \frac{M_s}{\rho_s}\ ,\ V_m = \frac{M_m}{\rho_m},\ V_C = V_f + V_S + V_m\ ,\ v_f = V_f/V_C\ ,v_s = V_S/V_C\ ,v_m = V_m/V_C$$

Where;

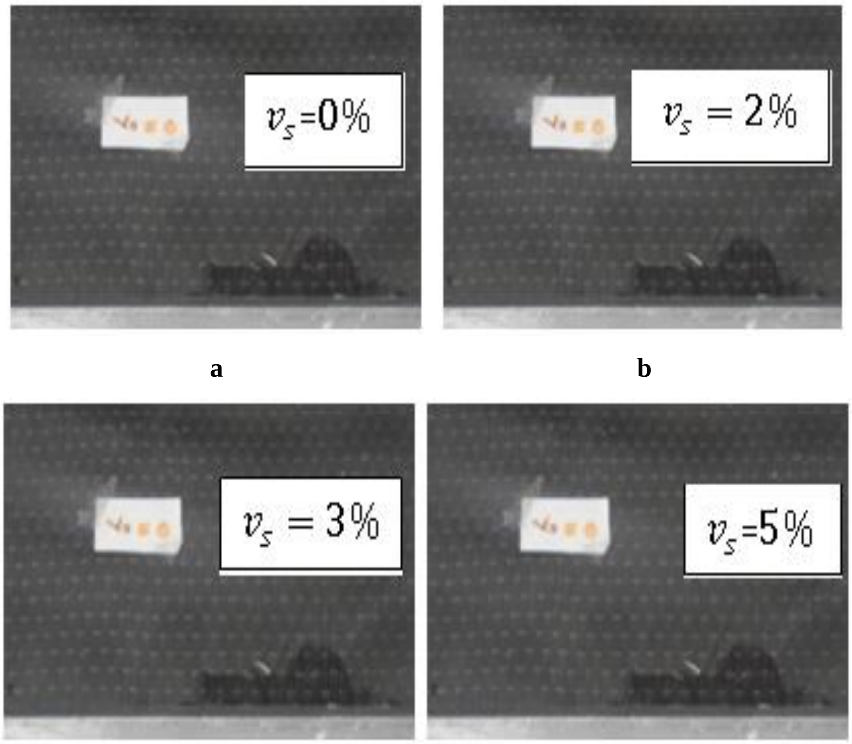
M_c,M_f, $M_s$represent mass of hybrid composite plate, carbon fiber and steel in (g) respectively.

ρ_f, ρ_s, $\rho_m$represent densities of carbon fiber, steel and matrix in(g/cm^3) respectively.

V_c, V_f, V_m, V_srepresent volumes of composite plate, carbon fiber, matrix and steel in (cm^3) respectively.

v_f, v_s, v_m representvolume fractions of carbon fiber, steel and matrix respectively.3-3. Types of plates.

All types of plates investigated in this study are in the form of simply-supported from four sides. The nominal dimensions of the plate is (24 cm length, 24 cm width and 0.6 cm thickness) with volume fraction of steel is (0%, 2%, 3%, 5%) for each plate respectively. The types of the layup of the plate under the investigation are symmetric cross ply (0 90 90 0) as shown in Figure 2.



a b

c d

Figure 2: Laminate Hybrid Composite Plates

Elastic Plastic Properties of the Composite Plates Hybrid with Steel

A method proposed by Victor B. [8] is used for the mechanics modeling of steel hybrid composite and according to this method; the mechanical properties in the third direction are the same as that in the second direction because the ply is transversely isotropic. Therefore, a total of five independent elastic constants are required. Note that the steel is an isotropic material, therefore

$$E_{S11} = E_{S22} = E_S\ ,\ G_{S12} = G_{S23} = G_S = \frac{E_S}{2(1+v_S)} \text{ and } \nu_{s12} = \nu_{s23} = \nu_s. \quad (1)$$

The resultant equations for the elastic properties of composite (fiber – matrix) laminate plate for longitudinal modulus are.

$$E_1^c = E_m v_m + E_{1f} v_f \tag{2}$$

For the transverse modulus

$$E_2^c = E_3^c = \frac{E_m}{[1-\sqrt{v_f}\left(1-\frac{E_m}{E_{2f}}\right)]} \tag{3}$$

For the shear modulus

$$G_{12}^c = \frac{G_m}{[1-\sqrt{v_f}\left(1-\frac{G_m}{G_{12f}}\right)]}, \quad G_{23}^c = \frac{G_m}{[1+\sqrt{v_f}\left(1-\frac{G_m}{G_{23f}}\right)]} = G_{13}^c \tag{4}$$

The poison's ratio

$$\nu_{12}^c = \nu_m v_m + \nu_f v_f \tag{5}$$

And the elastic properties for laminated composite plate hybrid steel

$$E_1^h = E_1^c v_c + E_s v_s, \qquad E_2^h = \frac{E_2^c}{[1-\sqrt{v_s}\left(1-\frac{E_2^c}{E_s}\right)]} \tag{6}$$

$$G_{12}^h = \frac{G_{12}^c}{[1-\sqrt{v_f}\left(1-\frac{G_{12}^c}{G_s}\right)]}, \qquad \nu_{12}^h = \nu_{12}^c v_c + \nu_s v_s \tag{7}$$

In these equations (1)-(7), the superscript, 'c' identifies the composite medium (fiber and matrix), and 'h' identifies the hybrid medium (composite and steel), while the subscripts '*m*' and '*f*' refer to the matrix and the fibers, respectively. The subscript '1' and '2' refer to the longitudinal along the (fibers) and transverse directions respectively. Other notations are as follow:

E= modulus of elasticity, *G*=shear modulus, *ν*=poison's ratio, *v*= volume fraction, where the subscript 's' identifies the steel. The results are listed in table 2.

Table 2: Elastic Properties of Hybrid Composite Plates

Properties	Value			
	v_s=0%	v_s=2%	v_s=3%	v_s=5%
Elastic modulus E_1^h(GPa)	23.2	28.16	30	36.4
Elastic modulus $E_2^h = E_3^h$ (GPa)	3.9	4.63	4.8	5.3
Shear modulus in plane 1-2 $G_{12}^h = G_{13}^h$ (GPa)	2.22	2.61	2.7	3
Shear modulus in plane 2-3 G_{23}^h (GPa)	2.07	2.44	2.53	2.78
Poisson ratio in plane 1-2 $v_{12}^h = v_{13}^h$	0.336	0.334	0.333	0.33
Poisson ratio in plane 1-2 v_{23}^h	0.0057	0.055	0.053	0.048
Density (Kg/m^3)	1161.5	1316.5	1392.8	1625

Experimental Test

The analysis of response signal is read from digital storage oscilloscope to FFT function by using **Sig-View** program to get the natural frequency of the plate as shown in Figure 3.This done by supporting the composite plate in a simply-supported and fixing the accelerometer in the center of the plate. The impact hammer is used to give the input load to the specimen and the signal captured by the accelerometer and is amplified by an amplifier. This signal stored in computer as an excel file then transformed to sig-view program to obtain natural frequency.

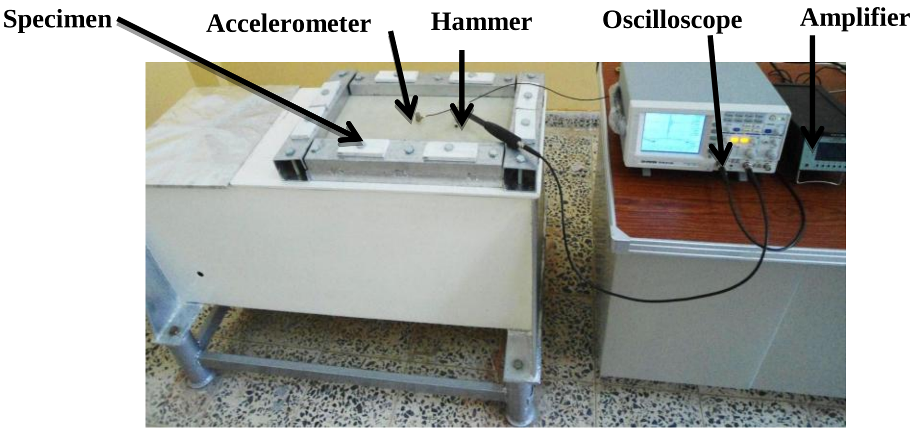


Figure 3: Experimental Set up for Modal Testing of a Simply-Supported Composite Plate Hybrid Steel

RESULTS AND DISCUSSIONS

Table 1 (3) shows the experimental natural frequencies obtained by free vibration test for all laminated simply supported previously mentioned. Figures (4a) to (4d) present the 1st natural frequencies obtained experimentally for the hybrid laminated plates of steel volume fraction 0%, 2%, 3% and 5% respectively.

Also these plates modeled using finite element method in order to get the natural frequency and mode shapes.

The plates are discretized using (shell 99) finite element available in the package ansys 11.0. This element has 8 nodes.

The lamina is considered to be linear elastic and generally orthotropic therefore, the concept of engineering constants is used to describe the lamina elastically. The elastic properties of the lamina are required as input parameters for the ansys. The properties are E_1, E_2 , E_3, G_{12} , G_{13} , G_{23}, ν_{12} , ν_{13} and v_23 which are given in table 2.

The results obtained by ansys are presented in table 3, for the first mode un-damped natural frequencies

Table 3: Natural Frequencies (Hz) from Ansys and Experimental Test

v_s%	1st Mode		
	Ansys	Exp.	% Diff.
0	68.637	72	4.7
2	70.502	73.3	3.8
3	70.552	74.2	4.9
5	72	75	4

From the results of table 3, it has been found that the experimental results show a good agreement with Ansys values (maximum difference equal to 4.9%), proving that the steel has influence on the dynamic behavior of the laminated plates. From the experimental results, it is observed that the increasing the steel volume fraction from 0% to 5% increases the natural frequency by about 4.6 % (i.e. from 68.637 to 72 Hz)

From these results, it is possible to verify the influence of steel volume fraction on the free flexural vibration of laminated plates. It is found that the maximum flexural frequency occurs at v_s= 5% and the minimum occurs at v_s= 0%. This can explained by the fact that the steel volume fraction v_s= 5% is more appropriate to flexural loads.

Variation of the lowest flexural frequencies with respect to steel volume fraction of laminated plates is presented in figure 5. Also the experimental frequencies are plotted against steel volume fraction of laminated plates.

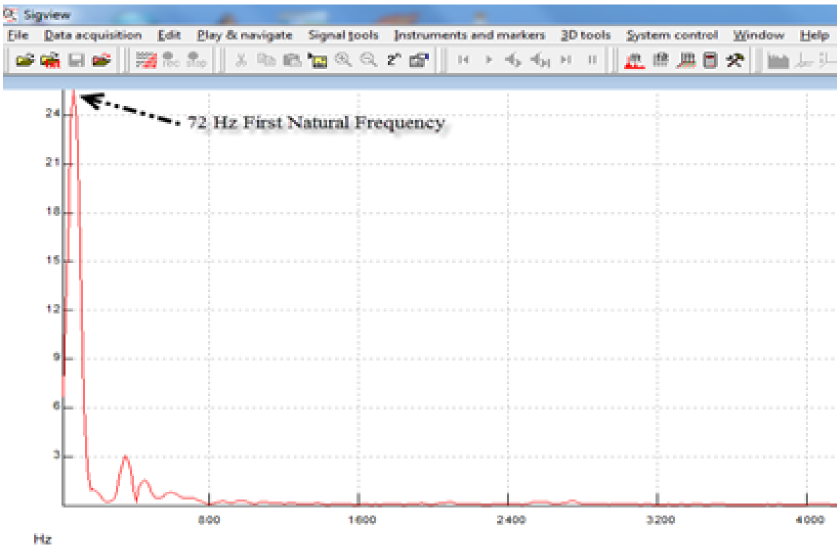


Figure 4a: 1st Natural Frequency Obtained by Experimental Test for Hybrid Laminated Composite Plate of v_s =0%

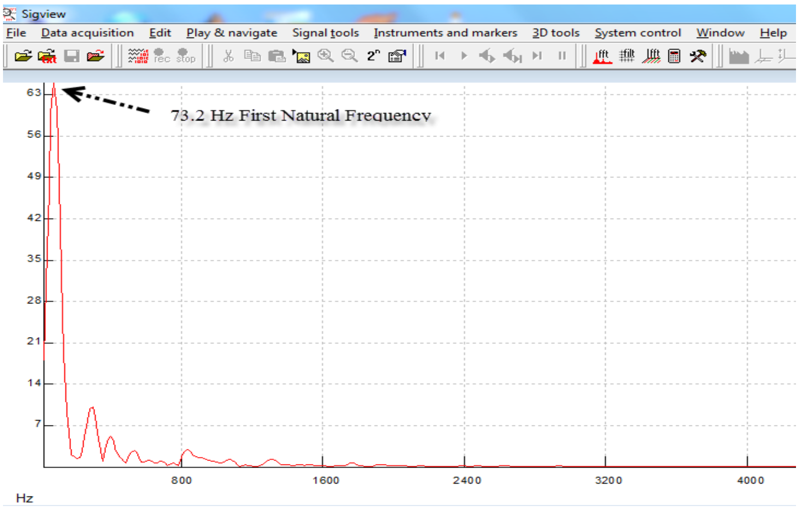


Figure 4b: 1st Natural Frequency Obtained by Experimental Test for Hybrid Laminated Composite Plate of v_s =2%

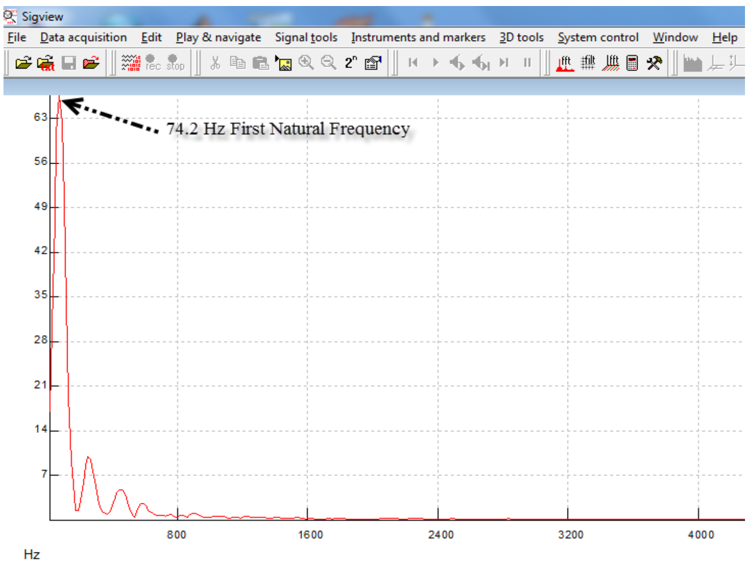


Figure 4c: 1st Natural Frequency Obtained by Experimental Test for Hybrid Laminated Composite Plate of v_s =3%

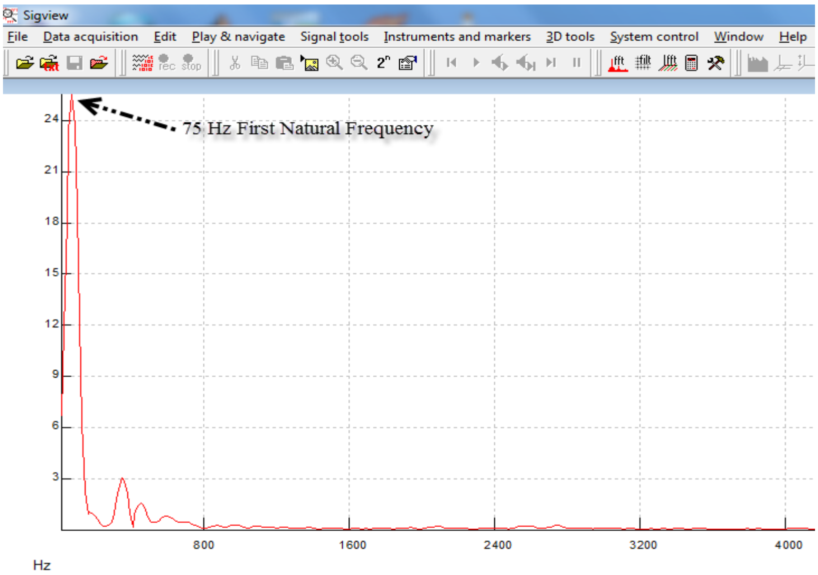


Figure 4d: 1st Natural Frequency Obtained by Experimental Test for Hybrid Laminated Composite Plate of v_s =5%

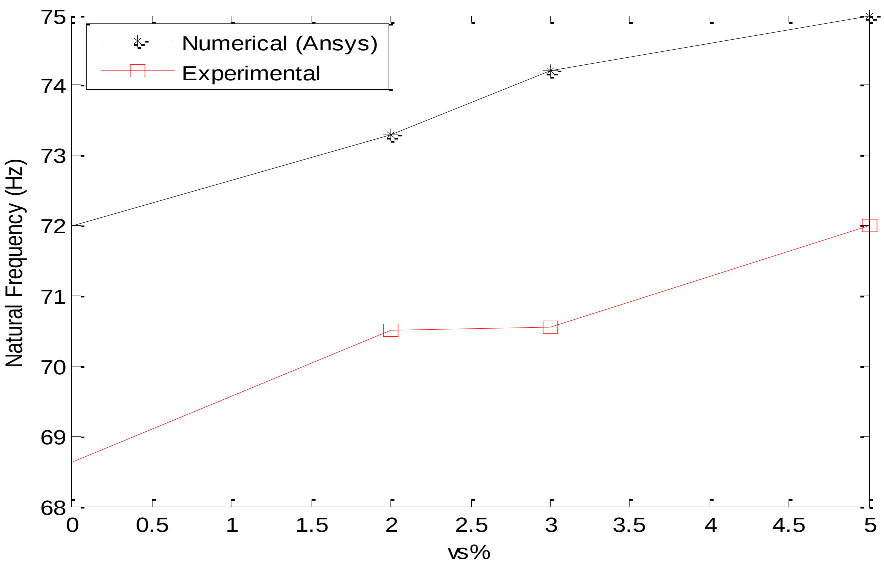


Figure 5: Variation of First Natural Frequency with Respect to Steel Volume Fraction for Hybrid Composite Plates

With relation to the deviation of the numerical results in relation to the experimental ones, some possible measurement errors can be pointed out such as: measurement noise, positioning of the accelerometer and their mass, non- uniformity in the specimen properties (voids, variations in the thickness, nom-uniform surface finishing). Such factors are not taken into account during the numerical analysis.

CONCLUSIONS

The main conclusions that can be drawn from this investigation are:

- The change in steel volume fraction yield to different dynamic behavior of the plates that is, different natural frequencies for the same boundary conditions
- As the steel volume fraction increases, the natural frequencies increase, with maximum value at v_s=5%.
- The results from Ansys showed a good agreement with the experimental values.

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